Topic E – Enviro Chemistry Part 3 – Greenhouse Effect

IB Chemistry

Topic E – Enviro

Hodder Ed - Talbot

E3 Greenhouse effect - 1.5 hours

- E.3.1 Describe the greenhouse effect. (2)
- E.3.2 List the main greenhouse gases and their sources, and discuss their relative effects. (3)
- E.3.3 Discuss the influence of increasing amounts of greenhouse gases on the atmosphere. (3)

E3.1 – Greenhouse Effect

- E.3.1 **Describe** the greenhouse effect. (2)
- *Greenhouse gases allow the passage of incoming solar short-wavelength radiation but absorb the longer-wavelength radiation from the Earth. Some of the absorbed radiation is re-radiated back to Earth.*
- ***TOK:*** *Some people question the reality of climate change and question the motives of scientists who have "exaggerated" the problem. How do we assess the evidence collected and the models used to predict the impact of human activities?*

E3.1 – Global Warming

- The **greenhouse effect** is the cause of the phenomenon of **global warming** in which the average temperature of Earth rises, causing various environmental disasters
- The greenhouse effect itself is absolutely necessary for the Earth to regulate its temperature at a habitable level.
- Humans are thought to impact this delicate balance by disrupting the natural equilibrium in the atmosphere, causing the planet to become warmer

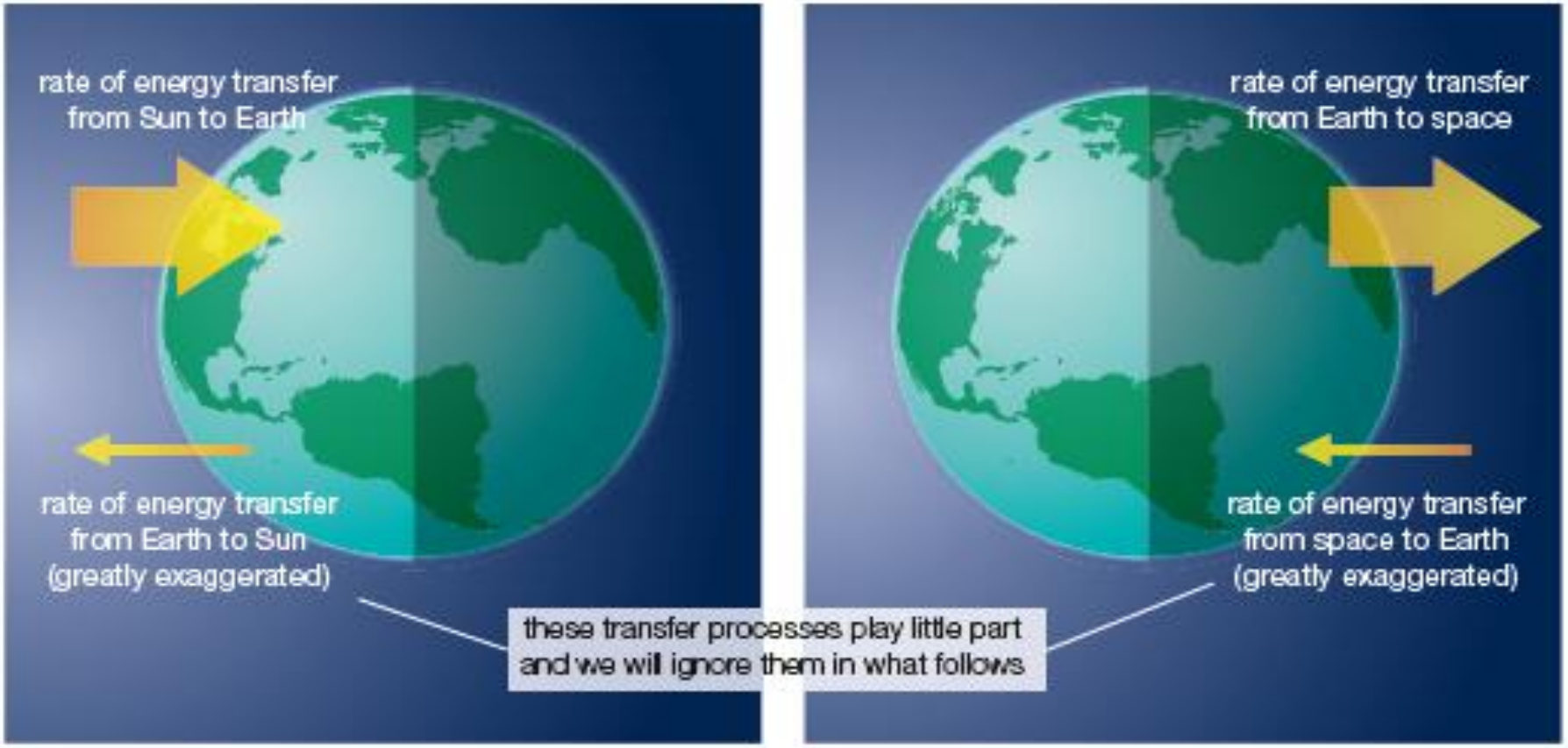
E3.1 – Earths "Average" Temp.

- *Average* temperature in the troposphere 14-15^{o}C
  - Maintained bc the energy incident on Earth (from sun), is balanced by the energy leaving Earth (to space)
- Most radiation from the sun is in the visible region, also along with "near UV" and near "IR radiation"
- Only 47% of energy directed at the earth is absorbed, remainder is reflected back to space
- The peak radiation is 500nm and is not absorbed by atmospheric gases so is absorbed and radiated by the earth to the rest of the atmosphere

E3.1 – Earth's Absorption

- When Earth absorbs energy, surface temperature rises, and energy flows from hot (earth) to atmosphere (cold), etc
- Once energy is re-radiated from the earth, it's no longer in the visible region, it's wavelength is much longer and in the infrared region
  - If all this energy released into space instead, our average atmospheric temp would be -20^{o}C
  - Gases such as H_2O and CO_2 help to re-radiated energy in the atmosphere and toward the earth as well.

E3.1 – Energy Transfer for Earth



- It can be seen that an increase in [IR absorbing gases] such as CO_2 and H_2O results in a decreased amount of energy escaping from the Earth by moving toward the surface

E3.1 – IR Vibrations

- Absorption and emission in the IR range occurs when molecules vibrate and rotate (their bonds)
  - Topic 02 – electrons jump energy levels when they absorb energy, emit when the fall down
  - Vibrational energy of molecules is similarly quantized
  - This can only occur for molecules with a **dipole**
    - O_2 and N_2 can't create temporary dipoles
    - H_2O absorbs strongly bc it is asymmetric

E3.1 – CO_2 Vibrations

- The shape of CO_2 is symmetrical and has no permanent dipole, BUT is able to have asymmetrical stretching and bending emissions:
  - Stretching: 2360 cm^{-1}
  - Bending: 670 cm^{-1}

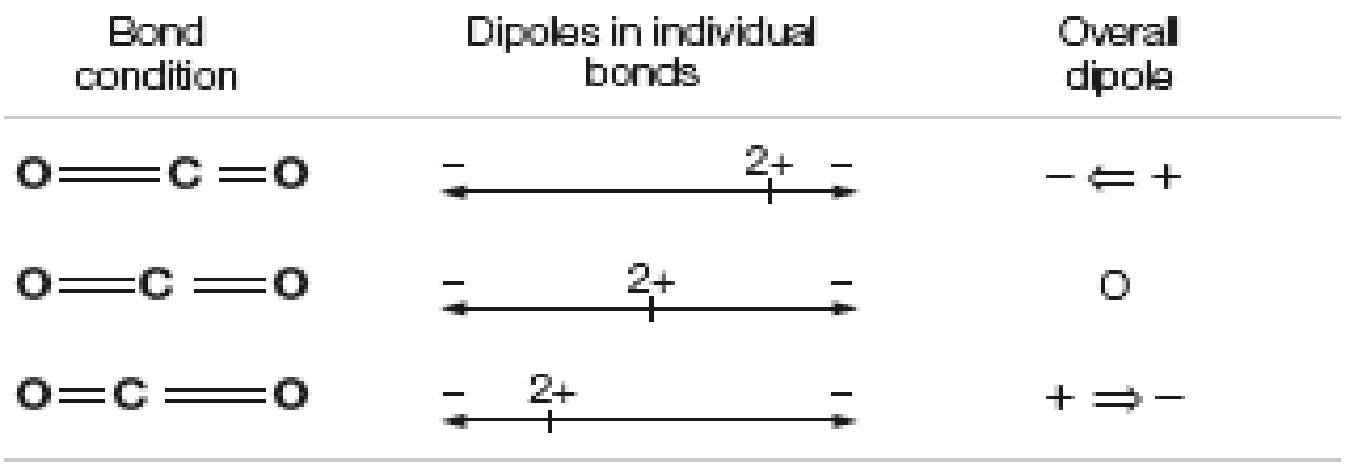


Figure 25.8 A diagram illustrating how the asymmetrical stretch (bending) leads to a change in the dipole moment of carbon dioxide

E3.1 – Emission and Absorption

- Both the emission and absorption of infrared are important to the greenhouse action of H_2O and CO_2
- Collisions between molecules may "excite" the molecules to higher energy levels.
- When molecules relax to a lower energy level, IR radiation is emitted.
  - Radiation may move up to space, or down toward surface
- Conversely a molecules may absorb IR
  - Collisions pass this energy to surrounding gas

E3.2 – Greenhouse Gases

- E.3.2 **List** the main greenhouse gases and their sources, and discuss their relative effects. (3)
- *The greenhouse gases to be considered are CH_4, H_2O, CO_2, N_2O and chlorofluorocarbons (CFCs). Their effects depend on their abundance and their ability to absorb heat radiation.*

E3.2 – Factors for GH Gases

- A contribution of a greenhouse gas to the warming of the atmosphere depends on three factors:
  1. The abundance of the gas in the atmosphere
  2. The ability of the gas to absorb infrared radiation
  3. The lifetime of the gas molecules in the atmosphere, before being removed by chemical processes

For CO_2, it's GWP=1

The 2nd and 3rd factors are often combined to give a figure called the **Global Warming Potential (GWP)**

E3.2 – Greenhouse Gases

- Major Contributors as Greenhouse Gases
  - Water vapor, H_2O
  - Carbon dioxide, CO_2
  - Methane, CH_4
  - Nitrous Oxide, N_2O
  - Chlorofluorocarbons, CFC's
  - Ozone, O_3

E3.2 – GH Gases – H_2O

- Most important GH Gas, mas a GWP of **0.1**
- Percentage of $H_2O(g)$ in atmosphere 1-4%, ranges
- Absorbs IR over a broad range of frequencies
- Increased atmospheric temperatures lead to more rapid evaporation of the oceans, and larger capacity of the air to carry water vapor (humidity)
- Estimates of H_2O's contribution to Global Warming is 36%-75%

E3.2 – GH Gases – CO_2

- Percentage of CO_2 in atmosphere is 0.035%
- CO_2 has a GWP of **1**.
  - More efficient than water in absorbing IR radiation
- Absorbs IR in a "window" that H_2O does not
- [CO_2] rise due to the following human activities:
  - Combustion of fossil fuels
  - Manufacture of cement ($CaCO_3 \rightarrow CaO + CO_2$)
  - Deforestation in tropics, lower rate of photosynthesis, meaning CO_2 is entering atmosphere more quickly than removed

E3.2 – GH Gases – CH_4

- Percentage in atmosphere $CH_4 = 1.7x10^{-4}$
- It's GWP is **25** (compare to H_2O=0.1 and CO_2=1)
- Estimates say 4%-9% contribution to Global Wíng
- It is removed from the atmosphere relatively quickly
- Formed when cellulose (plant fiber) decomposes anaerobically via bacteria $(CH_2O)_n \rightarrow -CH_4 + -CO_2$
- Occurs on large scale as a result of human actions:
  - Rice cultivation (paddy fields)
  - Fermentation of grass in cows, and rotting manure
  - Leaking gas pipelines
  - Fermentation of organic materials in covered landfills

E3.2 – GH Gases – N_2O

- GWP of **296**. It's less efficient at absorbing IR than CO_2 but it's high number comes from a long residence in the atmosphere
- Percentage in atmosphere 0.031%
- Accounts for 5% of Global W'ing effects
- Human activity only accounts for 10-12% of it's production, but anthropogenic NO_2 from:
  - Industrialized agriculture, N fertilizers
  - Industrialized livestock farming, poor handling of animal waste
  - Chemical industry, HNO_3 and nylon production

E3.2 – GH Gases – CFC's

- Chlorofluorocarbons (CFC's) have largely been replaced in aerosols, propellants, and refrigerants by **hydrochlorofluorocarbons (HCFC's)** and **hydrofluorocarbons (HFC's)**
  - These gases are less damaging to the ozone layer but still have GWP values much higher that CO_2 and are important contributors to global warming

E3.2 – GH Gases – O_3

- The production of ground level ozone has risen dramatically since the Industrial Revolution
- This ozone is formed by the action of sunlight on hydrocarbons and nitrous oxide from the burning of fossil fuels.
- This ozone eventually finds it's way to the troposphere and helps to increase the greenhouse effect.

E3.3 – Influence of Greenhouse Gases

- E.3.3 **Discuss** the influence of increasing amounts of greenhouse gases on the atmosphere. (3)
- *Examples include: thermal expansion of the oceans, melting of the polar ice-caps, floods, droughts, changes in precipitation and temperature, changes in the yield and distribution of commercial crops, and changes in the distribution of pests and disease-carrying organisms.*

E3.3 – Rising Sea Levels

- As atmospheric temperature increases, sea levels will rise for two reasons:
  - The increased atmospheric temperature causes accelerated melting
    - This does not include floating ice in the arctic as it already displaces water while it floats
  - As oceans warm up, the water in them will expand, occupying more volume (even minor amounts could be significant due to the quantity of water in the ocean!)

E3.3 – Glacier Retreat

- Glaciers undergo a seasonal melting and freezing as temperatures vary throughout the year.
- In the Himalayas glacial melt water is an important source of fresh water, feeing the rivers of South Asia
- Increased melting increases erosion and risk of flooding downriver, a particular problem in low-lying countries

E3.3 – Changing Patterns of Agriculture

- In temperate regions (such as Europe) yields of grain will most likely increase due to higher temperature, longer growing season and increased [CO_2] available for photosynthesis
- But, increased humidity and rainfall could lead to increased incidence of fungal crop diseases, and migration of tropical insects to higher altitudes.
- At higher latitudes, more workable land may become available due to thawing and temperature changes.
- Worldwide, the possibility of extreme weather increases the likelihood of ruined harvest

E3.3 – CO_2 Increases

- Atmospheric CO_2 levels have been recorded with increases shown at right →
- A comparison was also studied from data collected from the analysis of air bubbles trapped in Arctic ice.
  - Shows an increase in CO_2 content over the last 150 years or more

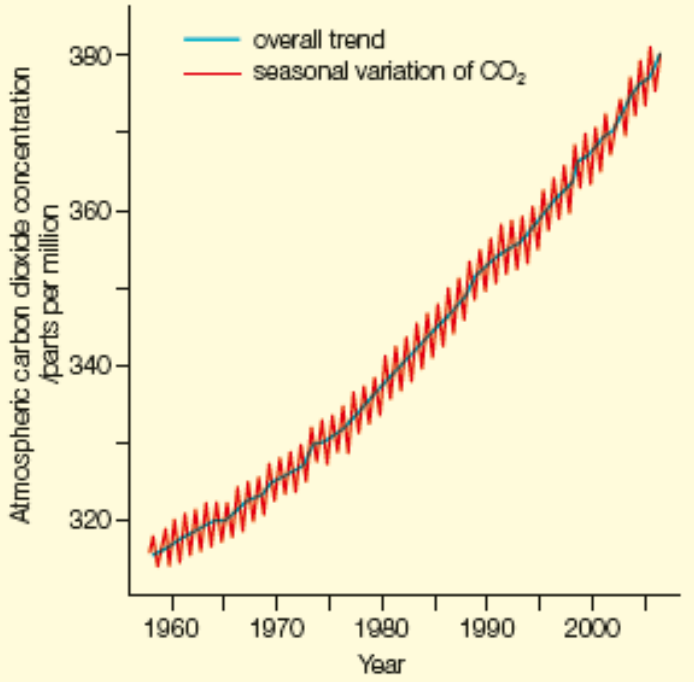


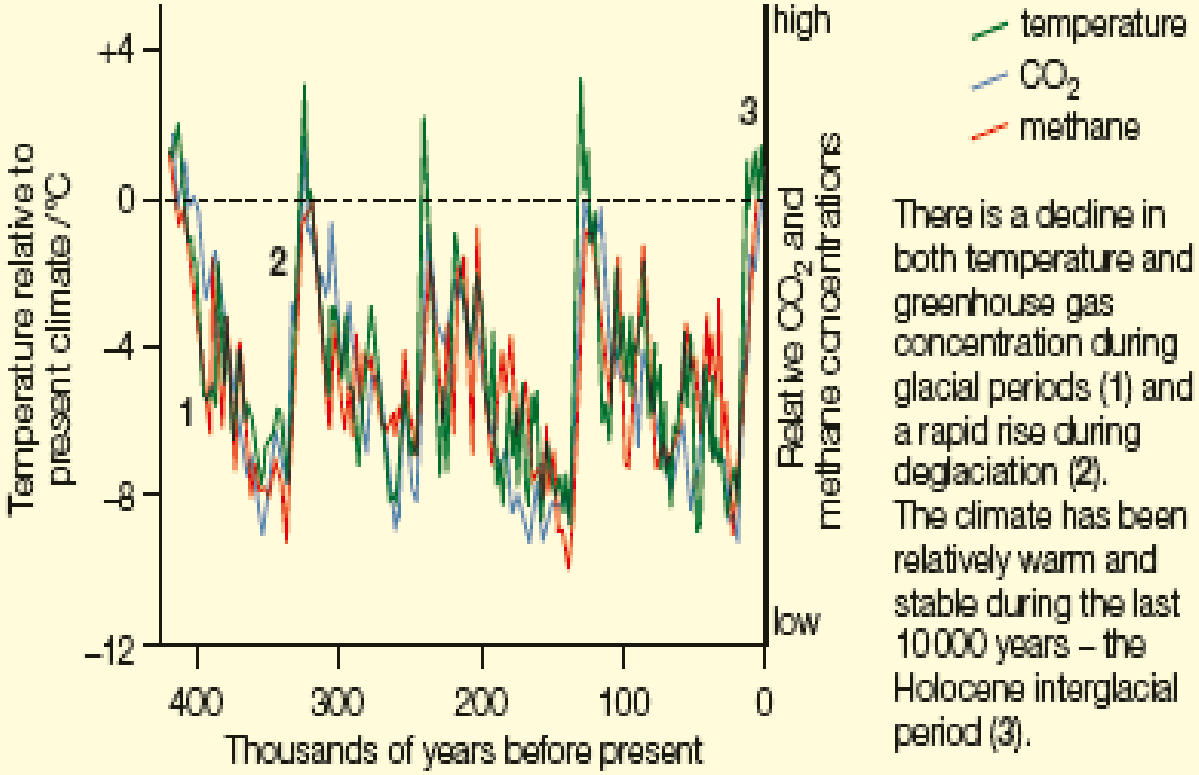
Figure 25.11 Atmospheric carbon dioxide levels recorded at Mauna Loa, Hawaii, 1957–2005

E3

E3.3 – Greenhouse Gas Correlation to Temperature Change

- Analysis of polar ice in the Greenland Ice Core Project, showed evidence for long-term climate changes (correlated to CO_2 and CH_4)

Evidence for long-term climate change came from the Greenland Ice Core Project. A research group drilled into the polar ice and analysed samples from different depths. The deeper the ice sample, the older the ice. The atmospheric temperature at the time the ice was laid down (Figure 25.10) can be inferred from the characteristic profile of isotopes of hydrogen and oxygen present, determined by mass spectrometry (Chapter 2).



There is a decline in both temperature and greenhouse gas concentration during glacial periods (1) and a rapid rise during deglaciation (2). The climate has been relatively warm and stable during the last 10 000 years – the Holocene interglacial period (3).

Figure 25.10 The three types of data recovered from the Vostok ice cores over 400 000 years of Earth history